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State-of-the-Art Flue Gas Cleaning
Technologies for MSW (Municipal
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STATE-OF-THE-ART FLUE GAS CLEANING TECHNOLOGIES FOR
MSW COMBUSTION

by

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ABSTRACT

The control of air pollutants from the combustion of municipal solid waste (MSW) has evolved from none or only particulate control to current systems controlling acid gases, trace organics, trace heavy metals, and nitrogen oxides as well as particulate matter. Both in-furnace and post-combustion control methods for limiting one or more of these pollutants are discussed. Test results for various control technologies are reported. Recent control technology applications and trends are noted.

INTRODUCTION

Much design and operating experience on municipal solid waste (MSW) combustion has been gained in Japan and Western Europe over the past decade as the volume reduction of wastes has been stimulated by the declining availability and increasing cost of landfills. Nearly 2000 MSW units in Japan and several hundred in Western Europe are now operating, with the trend now being waste-to-energy conversion rather than simply incineration to reduce volume. Technology developed in Japan and Western Europe has been beneficial to the U.S., where over 100 MSW combustion systems are now operational and a similar number are in the construction or conceptual development phase.

The reduction of waste volume by combustion results in air pollution, including pollutants not currently regulated by the U.S. EPA. Table 1 shows the U.S. standards along with those of several states and countries.¹ However, EPA has announced its intention to further regulate emissions from MSW combustors and proposes promulgation of these regulations in December 1990. Currently studies are underway to determine which pollutants to regulate and to what extent. As indicated in Table 1, classes of pollutants currently regulated by one or more of the entities listed include: trace organics (dioxins, total organics), acid gases (HCl, SO₂), trace heavy metals (Hg, Cd, Tl), and particulate matter. The listing in Table 1 is not intended to be complete. For example, West Germany regulates the emissions of more trace metals, and some U.S. states, as well as Japan and West Germany, have NO_x requirements/guidelines.

Noting the classes of pollutants that are currently regulated and their potential for regulation in the U.S.--on a national, state, or local level--the air pollution control strategy selected for a given plant should have the potential for multi-pollutant control, if costly retrofit or upgrading

is to be minimized in meeting future regulations. Residues, although small in volume relative to unburned wastes, contain concentrated pollutants requiring environmentally safe disposition. Since flue gas cleaning is the primary objective here, residue disposal will not be discussed.

EMISSION CONTROL TECHNOLOGIES

In-Furnace Methods

The major concern of in-furnace emission control is the destruction of combustible and toxic components. As part of a recent EPA report to Congress, good combustion practice guidelines were stated.² These guidelines, currently being reviewed in the regulatory development effort, address temperature control, overfire/underfire air mixes, turndown and start-up restrictions, CO and O₂ control, and other factors.

Limestone (CaCO₃) injection at a molar ratio of CaCO₃ to HCl of 1.2 into the furnace [700-950°C (1300-1750°F) zones] with HCl concentrations of 500-800 ppm is reported to reduce the HCl to 370-400 ppm and at a ratio of 4 to 100-130 ppm (see Figure 1). This method does not seem suited to a HCl removal requirement of 90% or outlet emission limits of 30-50 ppm, as required in some U.S. states, unless a more reactive sorbent is used. Figure 1 also shows the performance of in-duct injection of calcium hydroxide [Ca(OH)₂], but this will be discussed later under acid gas control in flue gases.

NO_x control methods as used in Japan are summarized in Table 2. Automatic combustion control, water spray into the furnace or combustor, flue gas recirculation, and ammonia injection listed in this table are in-furnace NO_x controls, while ammonia injection with a catalyst and a wet scrubber with oxidation are post-combustion NO_x control methods.

The first three methods control oxygen and temperature to limit NO_x formation. In the U.S., the thermal De NO_x method injects ammonia into the upper furnace to selectively reduce NO to N_2 .³ Since the ammonia/ NO_x reactions are very temperature sensitive, the ammonia injection location must be carefully chosen (see Figure 2). Injection location can also affect ammonia slip (i.e., the ammonia that does not react with NO_x).

Reburning with an auxiliary feed, such as natural gas or oil, is another NO_x control method and may be used in conjunction with flue gas recirculation. Its application to MSW combustors may be as shown in Figure 2. The stoichiometric ratio (SR_i) terms are for air/fuel mixtures, a value below 1.0 denoting a fuel-rich state. Sufficient fuel should be supplied at a low location in the furnace to produce a hot, oxygen-deficient zone. Overfire air injected over the reburning zone supports completion of the combustion process. Reburning can be combined with ammonia or urea injection to maximize NO_x reduction and also to promote destruction of organic compounds in the presence of high flame temperature and high concentration of flame radicals in the reburning zones.⁴

Particulate Matter Control

The predominant method for particulate control in MSW combustion is the electrostatic precipitator (ESP). A low emission level [$<45 \text{ mg/Nm}^3$ (0.02 gr/dscf)] can be attained by an ESP with a high ratio of collector plate surface area to gas flow volume, such as $170 \text{ m}^2\text{-min/Nm}^3$ ($52 \text{ ft}^2\text{-min/ft}^3$) or larger.⁵

Fabric filters are seldom used without upstream flue gas humidification (quenching) or sorbent injection to preclude bag failures caused by hot gases, spark carryover, or sticky particles from the furnace/boiler. They are capable of controlling particulate matter to below 45 mg/Nm^3 without operational upsets related to varying MSW and ash compositions that can adversely affect ESP performance.

Venturi scrubbers using water, used in early MSW incinerators, are not sufficiently effective to attain most current particulate control requirements as they remove 80 to 95% at normal operation. Very high pressure losses occur when venturis effectively remove fine particles. In addition, the high erosion and corrosion potential in venturis handling acid streams leads to costly operation and degraded reliability.

Acid Gas Control

Both dry and wet processes are used to remove acid gases (HCl , HF , and SO_2) from flue gas produced by MSW combustion. Here, dry and wet scrubbing means that the wastes from the process are dry and wet (slurry or sludge) products, respectively. In some countries, semi-dry or wet/dry scrubbing refers to a spray dryer (here an absorber because it receives an alkaline slurry or solution which is atomized into fine droplets that react with acid gases and are dried on contacting the surrounding hotter flue gas stream to produce dry powdery solids). Thus, the cooled flue gas leaving a spray dryer is unsaturated with water and carries entrained dried reaction solids and fly ash to the downstream particulate collector. Injecting a dry powdery sorbent, such as lime, into flue gas leaving the furnace/boiler effects acid gas removal, and the resulting dry reaction products are transported by water-unsaturated flue gas to the particulate collector. This latter process is universally called dry scrubbing, although humidification (quenching) of the flue gas may precede sorbent injection. In contrast, wet scrubbing produces a clean water-saturated flue gas whose temperature is somewhat lower than that of flue gas from semi-dry and dry scrubbing.

The simplest process for removing acid gases (HCl , HF , and SO_2) is dry alkaline sorbent injection into flue gas from the furnace/boiler

followed by particulate collection. If totally dry sorbents are injected into the flue gas duct or reactor, they require substantial contact time with the target flue gas pollutant to achieve high removal. Thus a fabric filter is preferred when high acid gas removal is required because the filter cake provides a greater sorbent/flue gas contact (residence) time than an ESP. However, flue gas humidification may be needed to ensure that spark carryover from the furnace/boiler does not pose a hazard to the fabric bags. Figure 3 shows a simple dry sorbent injection control system with the option for sorbent injection into the flue gas duct or into a circulating fluid-bed reactor.

In Japan, where lime injection into the flue gas duct is the most prevalent HCl control method on MSW combustors [100-200 tonnes/day (110-220 tons/day)], the ESP is preferred for particulate collection. However, except in special areas, the particulate standard (see Table 1) and HCl standard are readily achieved by this control method. For example, an inlet HCl concentration ranging from 600 to 800 ppmv (corrected to 12% O₂) would require an HCl removal ranging from 28 to 46% to meet the HCl standard of 430 ppmv. Also, SO₂ control is generally not required as the uncontrolled SO₂ concentration at Japanese MSW incinerators is 60-100 ppmv and, except in special areas, the standard approximates 100 ppmv.

A pilot scale study conducted for Environment Canada by Flakt-Canada indicated very effective acid gas control [>90% HCl and SO₂ removal, except for one test at 140°C (284°F)] when dry lime was injected into the reactor where the flue gas was humidified by water injection prior to contacting lime (see Figure 3).⁶ Particulate collection was by a fabric filter. The pilot system evaluated is similar to systems in use in Western Europe.¹

Spray dryer (semi-dry or wet/dry) absorption is more effective than dry sorbent injection since its approach to saturation temperature is lower, and acid gas removal increases with decreasing approach to saturation temperature. Waste heat recovery may precede the spray dryer to improve energy recovery from the combustion gases while attaining the desired approach to saturation temperature. A spray dryer absorption system is shown in Figure 4.

Pilot unit and commercial MSW combustion unit tests have demonstrated HCl removals of 90% or more and SO₂ removals exceeding 70% with lime spray absorption followed by fabric filters. Similar results have been obtained with lime spray dryer absorber/ESP systems. However, the data were for short-term tests, and data are needed on the long-term performance of these acid gas control systems on commercial units.

Wet scrubbers, preceded by an ESP with 99% or greater control, often use sodium hydroxide (NaOH) in MSW combustion applications and are particularly favored where high trace heavy metals control is desired in addition to acid gas control. A heat exchanger downstream of the wet scrubber (Figure 5) can be used to condense water vapor from the water-saturated flue gas, and (through cooling of the flue gas) limit the visible steam plume leaving the stack as well as remove submicrometer (submicron) particles and metallic vapors. In removing trace metals from the liquid scrubber effluent, the effluent is treated to precipitate the metals. The remaining liquid effluent may also require pH treatment prior to its discharge to a nearby water stream or body, if permitted.

A wet scrubber preceded by a spray dryer/particulate collector is shown in Figure 6. This system has two acid gas venturi scrubbers in series, the first being a water prescrubber for HCl removal and the second using NaOH for SO₂ removal. The liquid effluents from both scrubbers (from the first venturi after neutralization by lime) are pumped to the spray dryer, which serves

primarily to evaporate the liquids. The cooled flue gas leaves the spray dryer and passes through the fabric filter or ESP before entering the prescrubber. This system, now used in West Germany, is designed to operate with zero discharge of liquid effluent.

Wet scrubbers (Figure 5) are used on MSW combustion units in Japan and Western Europe. Both systems with wet scrubbers (Figures 5 and 6) can achieve 95% HCl removal, 90% SO₂ removal, and high removal of trace metals and organic compounds (dioxins/furans), and can be adapted to NO_x control. However, they are complex relative to dry and semi-dry scrubbers, the complexity increasing as the number of targeted pollutants increases. Table 3 compares the effectiveness of acid gas control systems.

Table 3 indicates that effective acid gas control can be attained with dry, semi-dry, or wet scrubbers. While HCl and HF control is relatively easy, SO₂ control is more difficult and is more effective with alkaline wet and semi-dry systems operating at and near flue gas saturation temperature, respectively.

Post-Combustion NO_x Control

While NO_x control on MSW combustion units is not normally required by national standards (e.g., 250/300 ppmv in Japan and 500 ppmv in West Germany), local or state (or similar) regulations may require it. NO comprises 95% or more of the NO_x in flue gas, and because of its low reactivity and water solubility, NO is probably the most costly and difficult component of NO_x to remove. Wet scrubbing control of NO_x, recently introduced in Western Europe and proposed in Japan, is based on either oxidation-absorption or absorption-reduction. Selective catalytic reduction (SCR), originally developed in Japan for coal- and oil-fired plants, has also been applied to MSW combustion units.

The oxidation-absorption approach to NO_x control involves adding an oxidizer, such as sodium chlorite (NaClO_2), to the scrubber (Figure 5) or prescrubber (Figure 6) to convert NO in the flue gas to NO_2 . For example, adding NaClO_2 to the first venturi scrubber (prescrubber) of Figure 6 and raising the pH to 3-4 result in NO's being oxidized to NO_2 , which is then absorbed in this and the following SO_2 scrubber. The oxidation-reduction method is used in several West German plants.⁷

Absorption-reduction to remove NO has been recently applied to MSW incinerators in West Germany.⁸ In this method, ferrous ions (Fe^{2+}) in the wet scrubber tie up NO in the liquid phase by forming ethylene diaminetetracetic acid (EDTA) complexes. These complexes react with HSO_3^- and SO_3^{2-} ions (from SO_2 absorption) to yield N_2 and SO_4^{2-} as reaction products. NO_x control with this method is reported to be about \$2-5 per tonne (\$1.80-4.50 per ton) of waste processed below that of oxidation-absorption and is based on the cost of chemicals only.

Selective catalytic reduction for NO_x control is illustrated for conventional (high temperature) and low temperature catalysts in Figure 7. In conventional SCR, acid gas and heavy metals control must precede SCR for high NO_x removal and avoidance of early catalyst failure due to poisoning. If the thermal penalty of prescrubbing for acid gas and metals removal is acceptable, then 80-90% NO_x can be removed with a NH_3/NO molar ratio of 1.0 and about 5 ppmv NH_3 slip.

The SCR system with low temperature catalyst, also shown in Figure 7, is being used on three MSW combustion units in Japan⁹ and has been selected for a proposed unit in California. The SCR unit follows the fabric filter of a dry lime injection system for HCl control, and the catalyst sees flue gas at

190-280°C (374-536°F) compared with 300-400°C (572-752°F) for conventional SCR. Performance tests in the Spring of 1987 on two new 59 tonne/day (65 ton/day) units served by one SCR unit gave 83% NO_x control (design value of 80%) with 140 ppmv NO_x at an inlet gas temperature of 200°C, an outlet NO_x value of 25 ppm, and a molar ratio of NH₃ to inlet flue gas NO_x of 1.05. Another test on a 136 tonne/day (150 ton/day) unit designed for 50% NO_x control indicated 57% NO_x removal when NO_x at 98 ppmv entered the SCR unit operating with flue gas at 246°C (475°F) and a molar ratio of 0.67. All NO_x concentration values given have been corrected to 12% O₂.

With a system similar to that in Figure 8, Mitsubishi claims: 98% HCl, 85% SO_x, and 80% NO_x removal with less than 20 ppm of each of these pollutants in the outlet flue gas; and 99% particulate (dust) removal with less than 20 mg/Nm³ (0.008 gr/dscf) in the outlet flue gas.¹⁰

Post-Combustion Organic Pollutant Control

Since the mechanisms of capturing dioxins, furans, and trace metals are unknown, their capture is not well understood. Their capture by condensation or attachment to particles is thought to be significant. Dioxin/furan attack and capture via caustic reagents and highly efficient particulate control is also suspected. Limited pilot plant data indicate that lime spray absorption followed by fabric filtration is highly effective for organic vapor control and superior to the spray absorber/ESP combination. In addition, lower flue gas temperature by spray absorption¹¹ and flue gas humidification before dry sorbent injection⁶ favors improved organics removal.

Limited data are available on control system efficiencies for dioxins and furans. Only outlet concentrations are reported for tests performed to determine compliance of commercial units with their permit conditions. Several tests

conducted recently for EPA in connection with compliance tests have collected both inlet and outlet organics data for lime spray absorption in combination with a fabric filter and an ESP, but the results are not yet available.

As noted earlier, the spray dryer absorber followed by fabric filtration was found to be more effective for organics control than when the spray-dried product was collected in an ESP. Table 4 summarizes these results, but the high and low temperatures noted were not given in Reference 11. It is believed that these temperatures were 150 and 110°C (302 and 230°F), respectively, based on subsequent information.

Heavy Metals Control

The removal of trace heavy metals from flue gas of MSW combustors is believed to be similar to that of organic pollutant control, where effective control of particles and low flue gas temperature are major factors. Sorbent reactions with metals, however, are not believed to be a major factor in metals control. The metals enter the air pollution control device as solids, liquids, and vapors, with some vapors becoming collectable solids and liquids as the flue gas cools. The flue gas temperature is usually decreased to 140°C (284°F) or less with lime spray absorption followed by particulate collection. With particulate removal by a fabric filter, 95% Hg removal was achieved with lime spray absorption, with and without solids recycle, compared with 94% Hg removal with dry lime injection (fluid bed reactor) at the same fabric filter inlet gas temperature (140°C).⁶ Other metals (arsenic, antimony, cadmium, chromium, lead, nickel, and zinc) were reduced by over 99% in both processes at the same temperature. While the lime spray absorption system was operated at only one temperature, the dry lime injection process was operated at lower [(110 and 125°C (230 and 257°F))] and higher temperatures [~209°C (408°F)] corresponding to

no gas cooling by humidification. Very high metals control, with the exception of mercury, was obtained at the other temperatures, similar to that at 140°C. For some unexplained reason, the mercury vapor concentration data indicated a higher Hg concentration at the outlet (610 $\mu\text{g}/\text{Nm}^3$ at 8% O_2) than at the inlet (450 $\mu\text{g}/\text{Nm}^3$ at 8% O_2) for the >200°C (>392°F) test. Comparison of metals control in the Environment Canada (EC) tests with those of other dry scrubbing systems confirmed the EC test results and also suggested that flue gas cooling can improve mercury removal from flue gas.

Reported metals control data generally reveal 95% or higher control for most heavy metals except mercury. Vapor-phase mercury removal has been reported to be 75-85% with the lime spray absorption/fabric filter system and 35-45% with the lime spray absorption/ESP system.¹² The spray absorber outlet temperature was 140°C (284°F) and the approach to saturation temperature was 85°C (153°F) in both scrubber systems.

With vapor condensation believed to be important to mercury control, wet scrubbers would appear to be better suited for this purpose than dry ones as they operate with flue gas saturation [$\sim 40^\circ\text{C}$ (104°F)]. It also appears that CaCl_2 , a product of calcium-based HCl scrubbers, is very active toward mercury and other metal vapors. Mercury collection methods are not well documented so that the choice of the most effective mercury control is still not uniform.¹³

SUMMARY

Wet or dry scrubbers are effective for controlling pollutants (acid gases, trace organics, trace heavy metals, and particulate matter) produced in burning MSW waste. The choice of scrubber type depends on the pollutants to be controlled and the degree of control required. Dry sorbent (lime) injection with an ESP is used extensively in Japan for acid gas control, but wet scrubbing

is preferred where high metals control is needed. The ESP/wet scrubber combination appears to be favored in West Germany for plants started up in the past decade and those expected to start up in the next several years. In the U. S., the lime spray absorption/fabric filter system is now frequently being selected for multi-pollutant control.

Acid gas removals of 90% or more have been achieved with a lime circulating fluid bed or lime spray dryer absorber preceding a fabric filter or ESP. Wet scrubbing preceded by an ESP is at least as effective as the systems noted when used to control acid gases. These systems are also effective for controlling organics and trace heavy metals, with mercury control appearing to be improved at lower temperatures and when a fabric filter rather than an ESP is used. Both the ESP and fabric filter can meet current particulate control requirements, but the fabric filter may have the edge for multi-pollutant control. More data, especially from commercial units, under long-term operation are needed to more fully quantify the performance of scrubbers designed to remove trace organic compounds and trace heavy metals.

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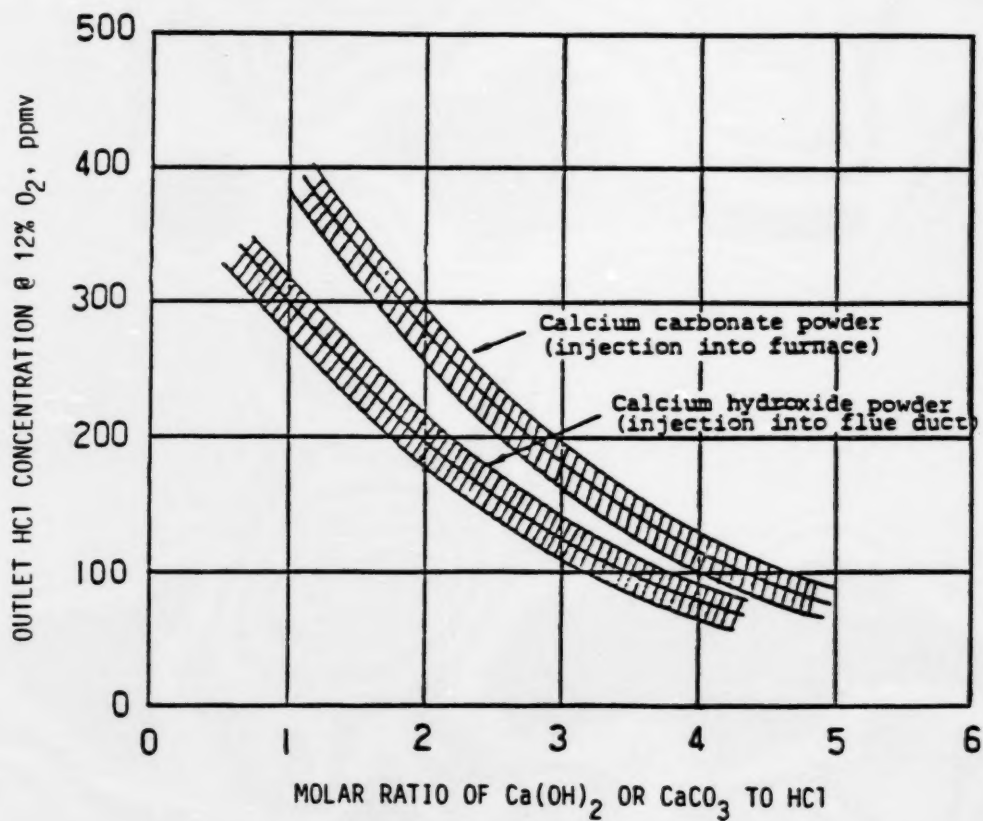


Figure 1. HCl removal by dry sorbent injection into furnace and flue gas duct. (Courtesy of Ishikawajima-Harima Heavy Industries Co., Ltd., Tokyo, Japan)

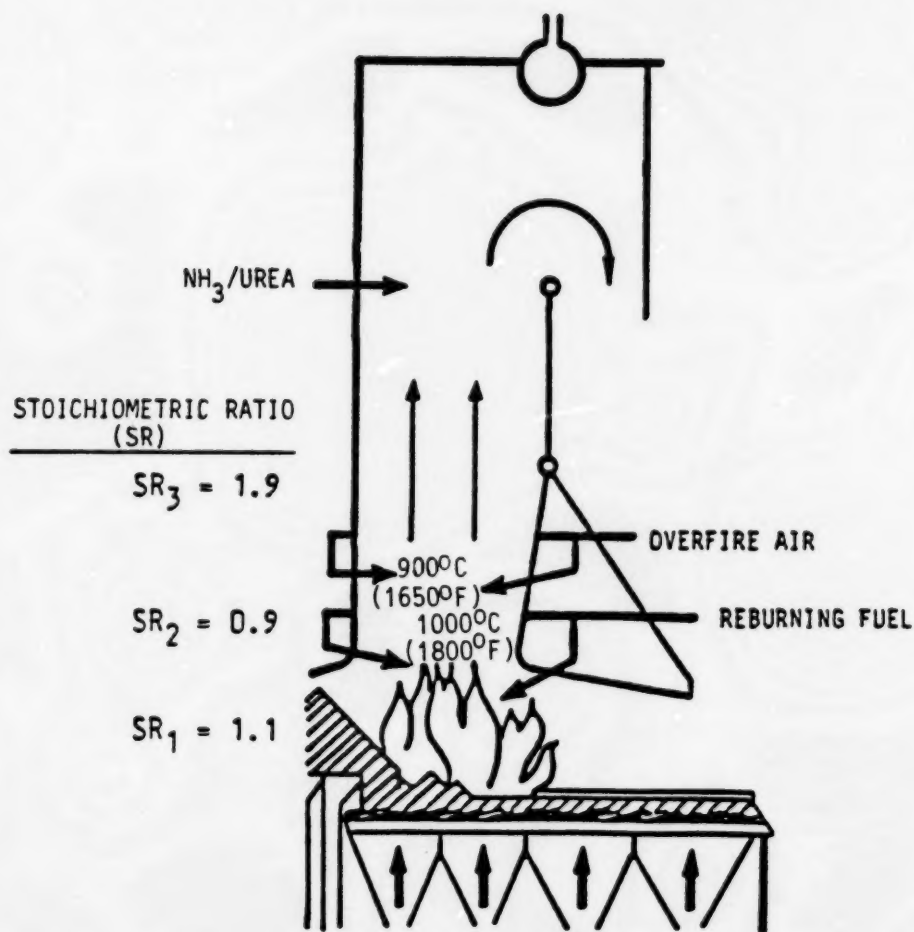


Figure 2. Reburning and Thermal DeNO_x in a MSW combustor.¹

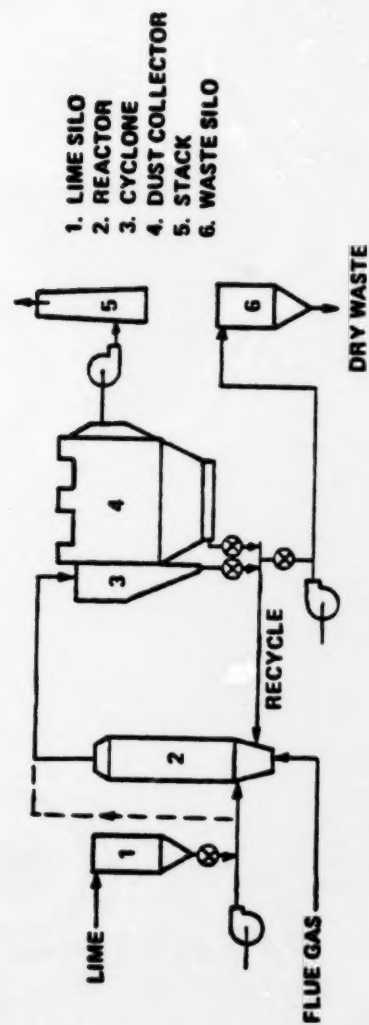


Figure 3. Dry sorbent flue gas cleaning by in-duct injection or a fluid-bed reactor.¹

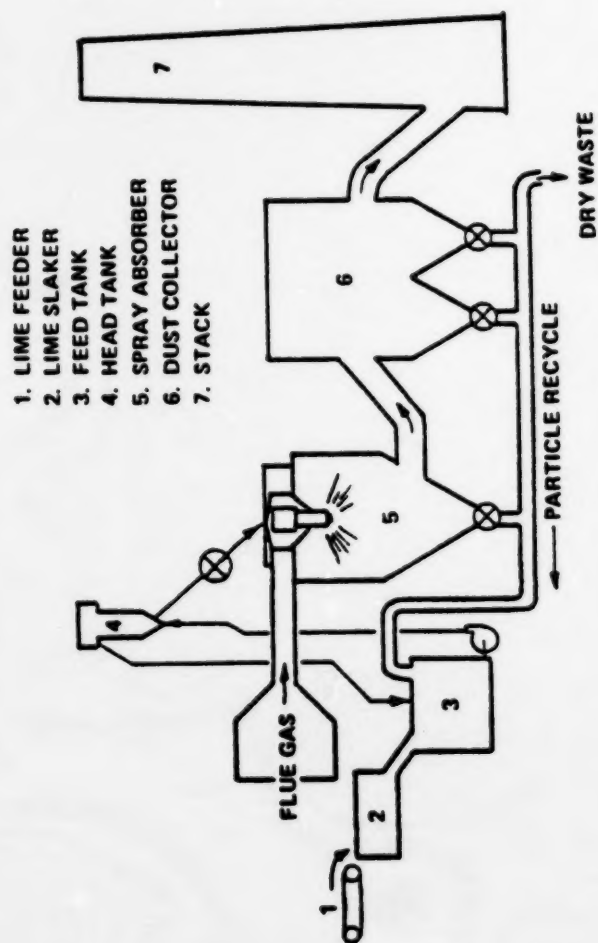


Figure 4. Spray dryer absorption (semi-dry or wet/dry) system.¹

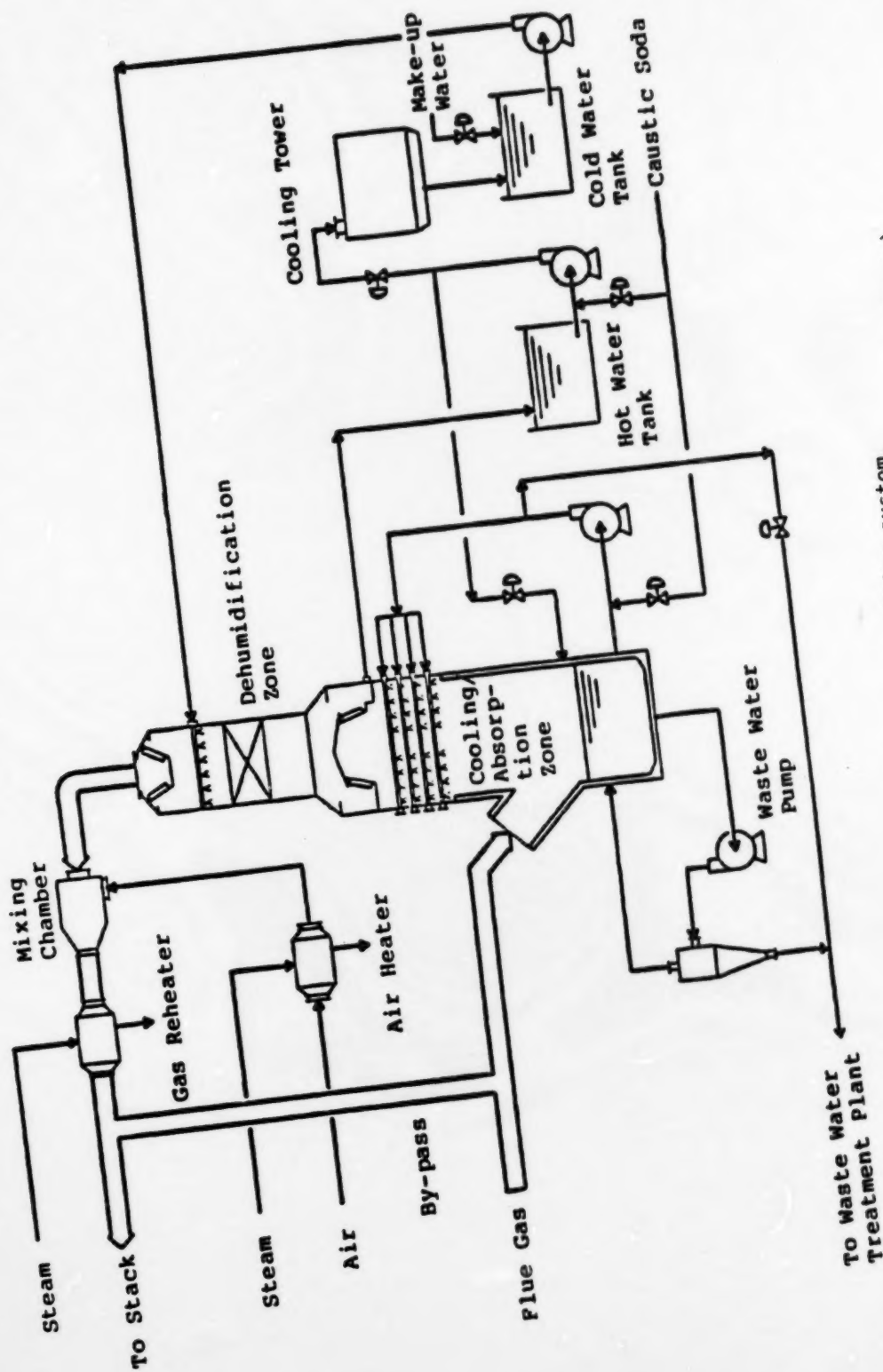


Figure 5. Wet flue gas scrubbing system.
(Courtesy of Hitachi Zosen Corp., Osaka, Japan)

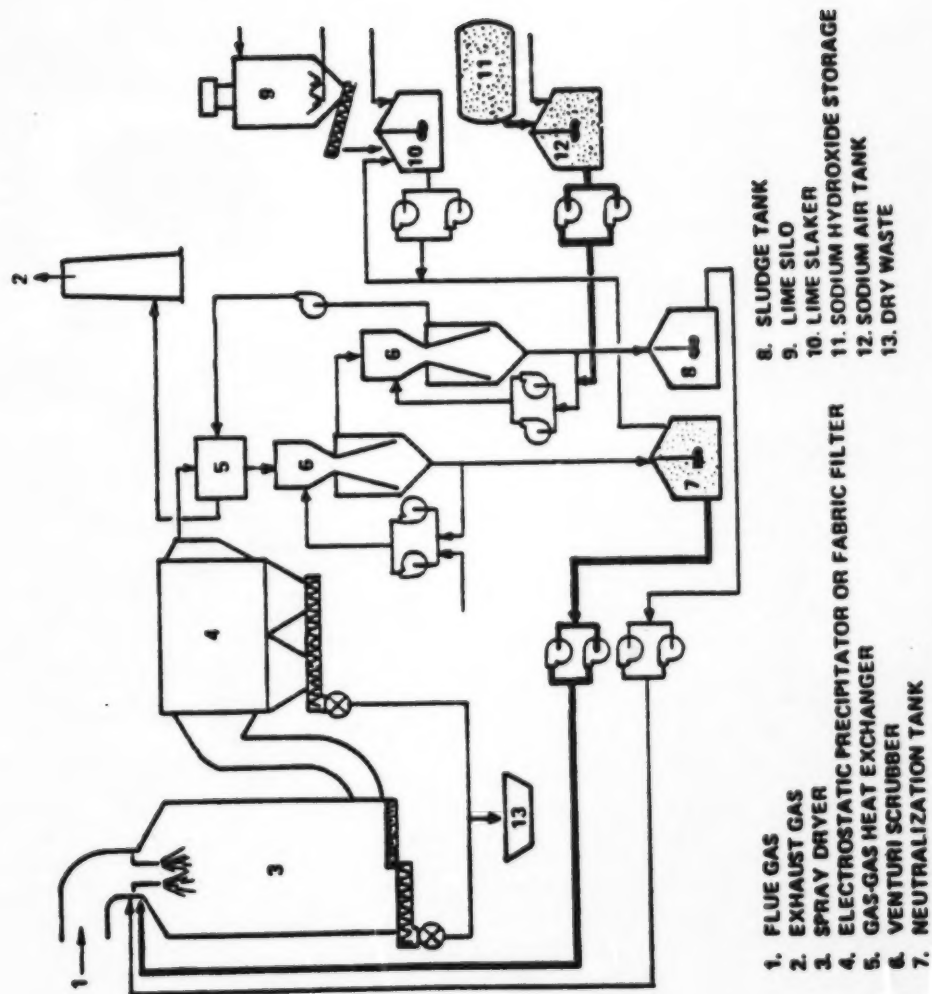


Figure 6. Semi-dry/wet scrubbing system.¹

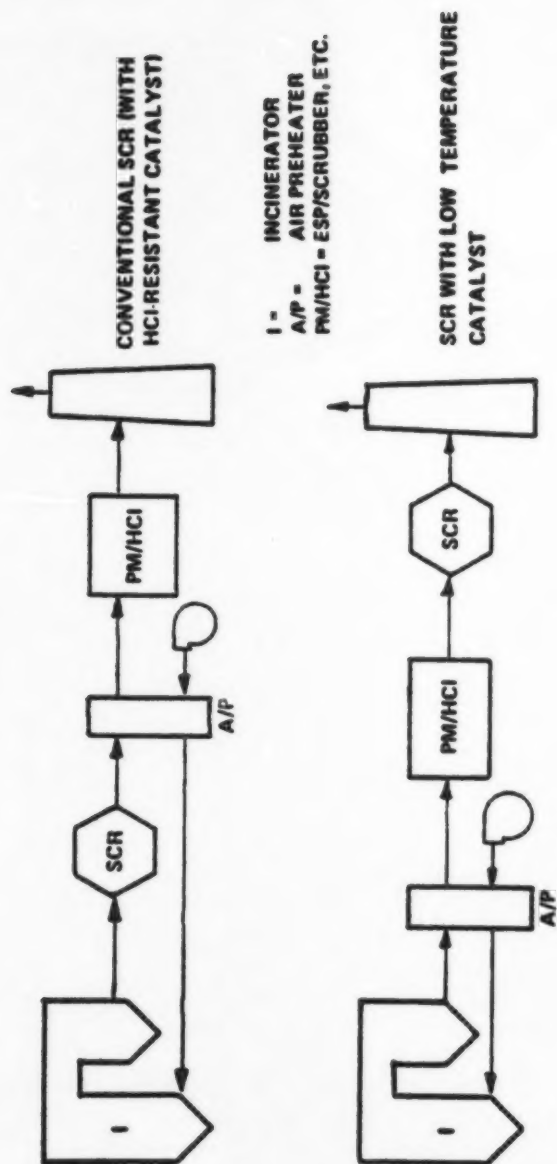


Figure 7. SCR options for MSW combustors.¹

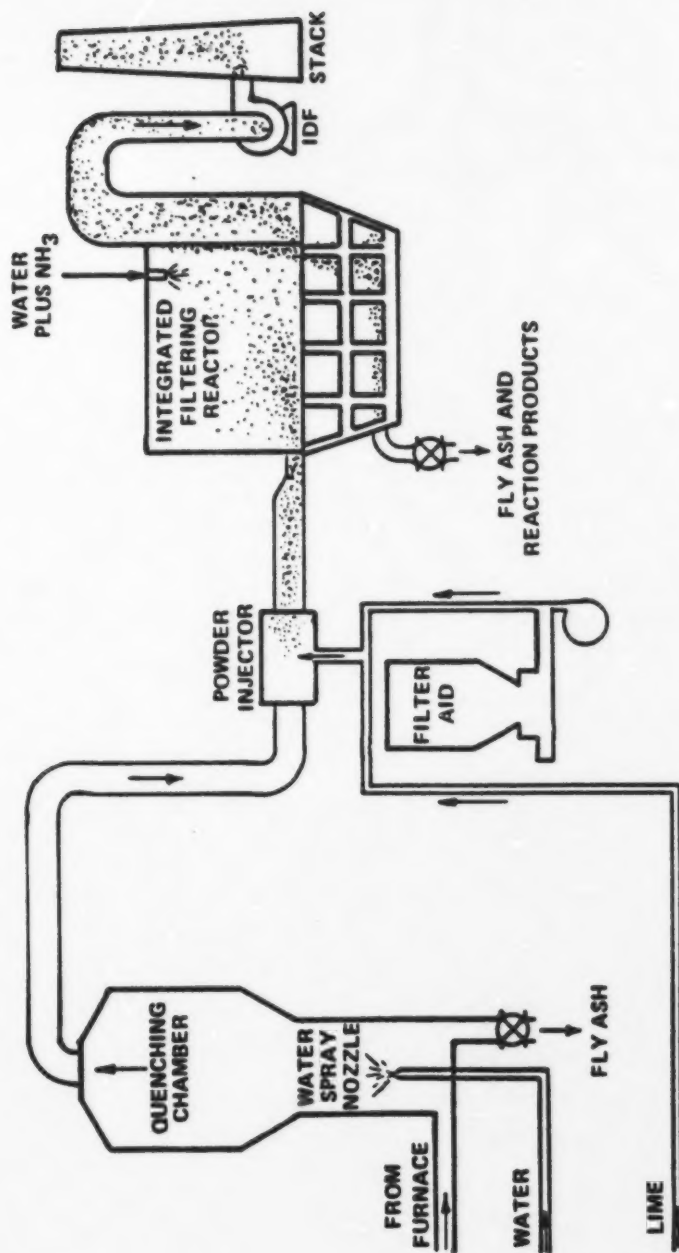


Figure 8. Integrated flue gas control system for waste to energy plant.

TABLE 1. SELECTED EMISSIONS STANDARDS FOR MUNICIPAL WASTE INCINERATORS¹

	U.S. ^a	California	Connecticut	Michigan	Japan	Sweden ^b	West Germany
Solid Particulate Matter gr/dscf (mg/m ³)	0.046 (113)	0.01c (25)	0.015 (37)	0.015 (37)	0.061d (150)	0.008 (20)	0.012 (30)
Carbon Monoxide, ppm	-----	-----	-----	113(24-hr avg)	-----	-----	80
Hydrogen Chloride	-----	30 ppmv (scrubbers required)	90% reduction	90% reduction	430 ppmv (700 mg/m ³)	63 ppmv (100 ng/ Nm ³)	31 ppmv (50 mg/ Nm ³)
Sulfur Dioxide, ppm	-----	30	170 (0.32 lb/ 106 Btu)	86	Varies ^e	New SO ₂ limits reduce all acids	35 (200 mg/ Nm ³)
Dioxins Measured as 2,3,7,8 - tetra- chlorodibenzo-p-dioxins (TCDD)	-----	f	g	-----	-----	Existing plants: 0.5-2.0 ng/ Nm ³ New plants: 0.1 ng/Nm ³	-----
Total Organics, mg/m ³	-----	-----	-----	-----	-----	-----	20
Mercury-Cadmium-Thallium mg/m ³ (includes vapors)	-----	-----	-----	-----	-----	0.08 (Hg only)	0.2
Gas Correction	12% CO ₂ dry	12% CO ₂ dry	12% CO ₂ dry	12% CO ₂ dry	12% O ₂ dry	10% CO ₂ dry	11% O ₂ dry

¹Revised NPS for pollutants scheduled to be proposed in 1989.

^aRevised NPS for pollutants scheduled to be proposed in 1989.

^bSwedish Environmental Protection Board's "Temporary Emission Goals," July 1986.

^cCalifornia regulations permit more stringent local limits. Two state guidelines are reported: 0.01 gr/dscf (25 mg/m³) for total solid particulates (TSP) and 0.008 gr/dscf (20 mg/m³) for particles less than 2 µm.

^dBased on continuous gas flows >25,280 scfm (40,000 m³/h). For flows <25,280 scfm, the particulate matter standard is 0.20 gr/dscf (500 mg/m³). For new plants in special areas, this standard is 0.033 gr/dscf (80 mg/m³) for plants having >25,280 scfm and 0.061 gr/dscf for those having <25,280 scfm.

^eBased on formula related to stack height and plant location. Typically, plant sulfur dioxide emissions range from 60 to 100 ppm so that control is not required except for new plants in special areas.

^fPollutant control requires use of the Best Available Control Technology (BACT), but no technology is specified.

^gThe use of dry gas scrubbers and baghouses is expected to improve removal over ESPs alone.

TABLE 2. NO_x CONTROL OPTIONS FOR MSW PLANTS
(Courtesy of Takuma Co., Ltd., Osaka, Japan)

Systems	Attainable Control Level (ppm v/v, dry, 12%O ₂)											Remarks
	150	120	100	90	80	70	60	50	40			
Uncontrolled	150	120										
Automatic Combustion Control		120	100	90								used with automatic combustion control
Water Spray in Combustion Chamber			100	90	80							ditto
Flue Gas Recirculation						70	60					ditto
Ammonia Injection without Catalyst						70		50				
Ammonia Injection with Catalyst									40			
Wet Scrubber with Oxidization										40		

Note: NO_x concentration is corrected by O₂ percentage in Japan, not by CO₂ percentage.

TABLE 3. EFFECTIVENESS OF ACID GAS CONTROLS (% REMOVAL)¹

Control System	Pollutant		
	HCl	HF	SO ₂
Dry Injection + Fabric Filter (FF) ^a	80	98	50
Dry Injection + Entrained Fluid Bed Reactor + ESP ^b	90	99	60
Spray Dryer Absorber + ESP ^c	95+	99	50-70
(Recycle) ^c	(95+)	(99)	(70-90)
Spray Dryer Absorber + Fabric Filter ^c	95+	99	70-90
(Recycle) ^c	(95+)	(99)	(80-95)
Spray Dryer Absorber + Dry Injection + ESP or FF ^d	95+	99	90+
ESP + Wet Scrubber ^e	95+	99	90+
Spray Dryer + Wet Scrubber(s) + ESP or FF ^e	95+	99	90+

^a T = 160-180°C (320-356°F)

^b T = 230°C (446°F)

^c T = 140°-160°C (284-320°F)

^d T = 200°C (392°F)

^e T = 40-50°C (104-122°F)

T = the temperature at the exit of the control device.

TABLE 4. SPRAY DRYER CONTROL OF SELECTED ORGANIC POLLUTANTS¹¹Control System (% Removal)

Compound	Full Scale	Pilot	Plant
	SD + ESP	SD + FF 150°C (302°F)	SD + FF 110°C (230°F)
<u>Dioxins:</u>			
tetra CDD	48	< 52	> 97
penta CDD	51	75	> 99.6
hexa CDD	73	93	> 99.5
hepta CDD	83	82	> 99.6
octa CDD	89	NA	> 99.8
<u>Furans</u>			
tetra CDF	65	93	> 99.4
penta CDF	64	88	> 99.6
hexa CDF	82	86	> 99.7
hepta CDF	83	92	> 99.8
octa CDF	55	NA	> 99.8

NOTES:

SD= spray dryer absorber

ESP= electrostatic precipitator

FF= fabric filter

Temperatures shown are flue gas values at the spray absorber outlet.

They were not given in Reference 11 and are based on subsequent information.